X64-14202

#13p
Code 2D
CAT. 12

NASA TT F-8736

CONTRIBUTION TO THE STUDY OF THE FORMATION OF SPORADIC E

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Translation of "Contribution a l'étude de la formation de E sporadique."
Centre National de la Recherche Scientifique (France),
Groupe de Recherches Ionosphériques,
Technical Note GRI/NT/18

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
MAY 1964

FACILITY FORM 602
N71-71327 (ACCESSION NUMBER)
(THRU)
13 (PAGES)
NONE (CODE)
(NASA CR OR TMX OR AD NUMBER)
(CATEGORY)

NATIONAL CENTER OF TELECOMMUNICATIONS STUDIES

NATIONAL CENTER OF SCIENTIFIC RESEARCH

INSTITUTE OF PHYSICS OF THE GLOBE

NASA TT F-8736

IONOSPHERIC RESEARCH GROUP

TECHNICAL NOTE GRI/NT/18

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Issy-les-Moulineaux,

5 March 1964.

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CONTRIBUTION TO THE STUDY OF THE FORMATION OF SPORADIC E

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I. INTRODUCTION

Dungey suggested in 1956 [1] that the earth magnetic field could influence the distribution of the charges in the F region in the presence of turbulence.

Whitehead [2] and Axford [3] took up this idea to explain the formation of the sporadic E strata, which appear in the regions of medium latitude.

The formation mechanism they proposed is suggested by two experimental results:

- On the one hand, the existence at the altitude at which Es appears of strong wind gradients.

- On the other, the correlation, shown by Heisler and Whitehead [4], between the fraction of time at which the critical frequency of Es exceeds 5 MHz and the modulus of the horizontal component of the medium magnetic field.

II. THEORY OF WHITEHEAD

Let us recall the formation mechanism proposed by Whitehead. In the ionospheric plasma the ions and electrons are dragged by the movement of neutral particles (wind). In the presence of the earth magnetic field a Laplace force drags these particles in a direction which is perpendicular to the plane formed by the wind vector and the magnetic field vector (the experiment shows that the vertical displacements are negligible before the

horizontal winds at the Es altitude). The direction of the drag of the particles changes with the direction of the wind and thus one understands, according to Fig. 1, that it is possible to have an accumulation of ions and electrons at the altitude at which the wind vector cancels itself.

This mechanism leads to the following establishment of the speed of the vertical displacement of the charges (it is supposed that the displacement speeds of the ions and electrons are equal) [2]:

$$V_z = \frac{\alpha \cos\theta}{1+\alpha^2}\left\{\left(\frac{1}{\alpha}\left(\bar{U}_{yg} - \bar{U}_{yf}\right) + \sin\theta\left(\bar{U}_{xg} - \bar{U}_{xf}\right)\right)c \right. \qquad (1)$$

$$\left. + \left(\frac{\sin\theta}{\alpha}\left(U_x - \bar{U}_{xf}\right) + \left(U_y - \bar{U}_{yf}\right)\right)a + \left(\frac{\sin\theta}{\alpha}\left(U_x - \bar{U}_{xg}\right) + \left(U_y - \bar{U}_{yg}\right)\right)b\right\}$$

Ux and Uy, which are function of z, are the components of the wind speed. They are defined in a system of axes (Fig. 2) in which Ox is directed from the East to the West, Oy from the South to the North, and Oz from down to up. θ is the magnetic slope and H is the intensity of the total field.

There is, on the other hand, $\alpha = \frac{\nu_i}{\omega_{H_i}}$ in which ν_i is the frequency of collision of the ions with the neutral particles and $\omega_{H_i} = \frac{eH}{mi}$ the angular gyrofrequency of the ions

$$\bar{U}_{yf} = \frac{-\int_{-\infty}^{\infty} f U_y \, dz}{\int_{-\infty}^{\infty} f \, dz} \qquad \bar{U}_{yg} = \frac{-\int_{-\infty}^{\infty} g U_y \, dz}{\int_{-\infty}^{\infty} g \, dz}$$

$$f = N \frac{\alpha}{1+\alpha^2} \qquad g = N \frac{\alpha^2}{1+\alpha^2}$$

N is the electronic density.

$$a = \frac{\left(\int_{-\infty}^{\infty} f \, dz\right)^2}{\left(\int_{-\infty}^{\infty} f \, dz\right)^2 + \left(\int_{-\infty}^{\infty} g \, dz\right)^2} \qquad b = \frac{\left(\int_{-\infty}^{\infty} g \, dz\right)^2}{\left(\int_{-\infty}^{\infty} f \, dz\right)^2 + \left(\int_{-\infty}^{\infty} g \, dz\right)^2}$$

$$c = \frac{\left(\int_{-\infty}^{\infty} f\,dz\right)\cdot\left(\int_{-\infty}^{\infty} g\,dz\right)}{\left(\int_{-\infty}^{\infty} f\,dz\right)^2 + \left(\int_{-\infty}^{\infty} g\,dz\right)^2}$$

$\overline{U}xf$, $\overline{U}_{yf}$, $\overline{U}_{xg}$, $\overline{U}_{yg}$ are averages of the horizontal speed within an interval of a given height. $\int f\,dz$ and $\int g\,dz$ are of the magnitude; it is inferred that the terms such as $\overline{U}_{xg} - \overline{U}_{xf}$ are negligible before $U_x - \overline{U}_{xf}$.

We have then:

$$\frac{dV_z}{dz} = \frac{\cos\theta\sin\theta}{1+\alpha^2}\frac{dU_x}{dz} + \frac{\alpha\cos\theta}{1+\alpha^2}\frac{dU_y}{dz} \qquad (2)$$

Whitehead [5] considers that $\frac{dVz}{dz}$ is the quantity which intervenes in a preponderant way in the formation of Es, at the altitudes at which Vz = 0. Then finding that below 120 km $\nu_i > \omega_{H_i}$, he writes:

$$\frac{dV_z}{dz} \simeq \frac{\cos\theta}{\alpha}\frac{dU_y}{dz} \qquad (3)$$

expression which shows that below 120 km the East-West component of the wind is more important than the North-South component.

We are going now to undertake a critical examination of this result.

III. DISCUSSIONS OF WHITEHEAD'S RESULT

1. In the redistribution mechanism there are accumulation of the ionization and formation of an Es stratum of small thickness at the altitudes at which $\frac{dVz}{dz}$ is negative and maximum in absolute value. As a matter of fact, when Vz moves from a big value to a clearly smaller value within a small height interval, more particles arrive in this zone than escape from it, and there is then accumulation without it being necessary that Vz cancel itself.

2. Let us consider the expression (1) of Vz. We can put it in a more workable vectorial form in observing that:

- the first term of (1) is negligible before the others,

- we have a+b = 1.

Let us present

$$a\bar{U}_{xf} + b\bar{U}_{x\sigma} = \bar{U}_{xfg} \qquad a\bar{U}_{yf} + b\bar{U}_{yg} = \bar{U}_{yfg}$$

We have

$$Vz = \vec{B} \cdot \vec{\Delta U} \tag{4}$$

where $\vec{B}$ and $\vec{\Delta}U$ have as components according to Ox and Oy:

$$\vec{B} \left(\frac{\sin\theta\cos\theta}{1+\alpha^2} , \frac{\alpha\cos\theta}{1+\alpha^2} \right)$$

$$\vec{\Delta U} \left(U_x - \bar{U}_{xfg}, \; U_y - \bar{U}_{yfg} \right) \tag{5}$$

The vertical speed gradient of the ions is:

$$\frac{dV_z}{dz} = \frac{d\vec{B}}{dz} \cdot \vec{\Delta U} + \vec{B} \cdot \frac{d(\vec{\Delta U})}{dz} \tag{6}$$

Let us neglect for the first approximation the first term of the second member; we have

$$\frac{dV_z}{dz} = \vec{B} \cdot \frac{d(\vec{\Delta U})}{dz} \tag{7}$$

$\frac{dVz}{dz}$ depends on two terms: the one, $\frac{d(\vec{\Delta}U)}{dz}$, characterized the gradient of the speed vector of the wind; the other, $\vec{B}$, characterizes the ionospheric plasma since it depends on the frequency of collision of the ions and the earth magnetic field. Between 80 km and 150 km of altitude, region of the appearance of the Es, $\vec{B}$ varies very perceptibly in direction and intensity.

Figure 3 gives the components of $\vec{B}$ according to axes oy and ox as a function of the altitude. They have been calculated according to (5), for Hammaguir (Sahara) where θ = 48 degrees and H = 0.386 gauss. The gyrofrequency ω_{H_i} is worth then 2.31×10^2 for the ion O^+.

The frequencies of collision $\nu_i(z)$ have been taken from Johnson [6] for a period of minimum solar activity.

It can be found [7] that the modulus of the gradient of the speed of

the ions is maximum when $\vec{B}$ and $\frac{d(\vec{\Delta}U)}{dz}$ are colinear. Figure 3 shows that up to 110 km, it is the East-West component of the wind which has a preponderant influence while at 140 km it is the North-South component. At the intermediary altitudes the two components intervene. The approached expression (3) is then valid only below 110 km.

3. This altitude limit finds itself also decreased if it is supposed that the ions carried are O_2^+. It is known [7], that between 100 and 150 km altitude the main ions are O_2^+, NO^+ and O^+ and that O^+ is not yet the preponderant component of the altitude of Es.

Figure 4 shows the variations of $\vec{B}$ as a function of z when O_2^+ is the ion carried; it is found that up to 105 km the East-West component is the most important but starting with 120 km the North-South component becomes preponderant.

It can be forecast that for a given wind profile, Es will be formed at different altitudes according as to whether the O^+ ions or the O_2^+ ones are carried.

4. As a first approximation, the term $\frac{d\vec{B}}{dz}$ of (6) has been neglected. A numerical calculation shows that if $\frac{d\vec{B}}{dz}$ is small before $\vec{B}$ it is not negligible in certain particular cases and that it can change perceptibly the value of $\frac{dV_z}{dz}$ as a function of z.

IV. CONCLUSION

The vectorial writing of (1) lends itself well to interpretation; it makes it possible to find easily the altitude of the formation of Es as a function of the wind profile.

On the other hand, we have shown that the choice of the ion carried influences the altitude of the appearance of Es; for the establishment of precise comparisons between the theory and the experimental results, it

would be desirable to know the ionic composition of the atmosphere in the zone in which Es forms itself

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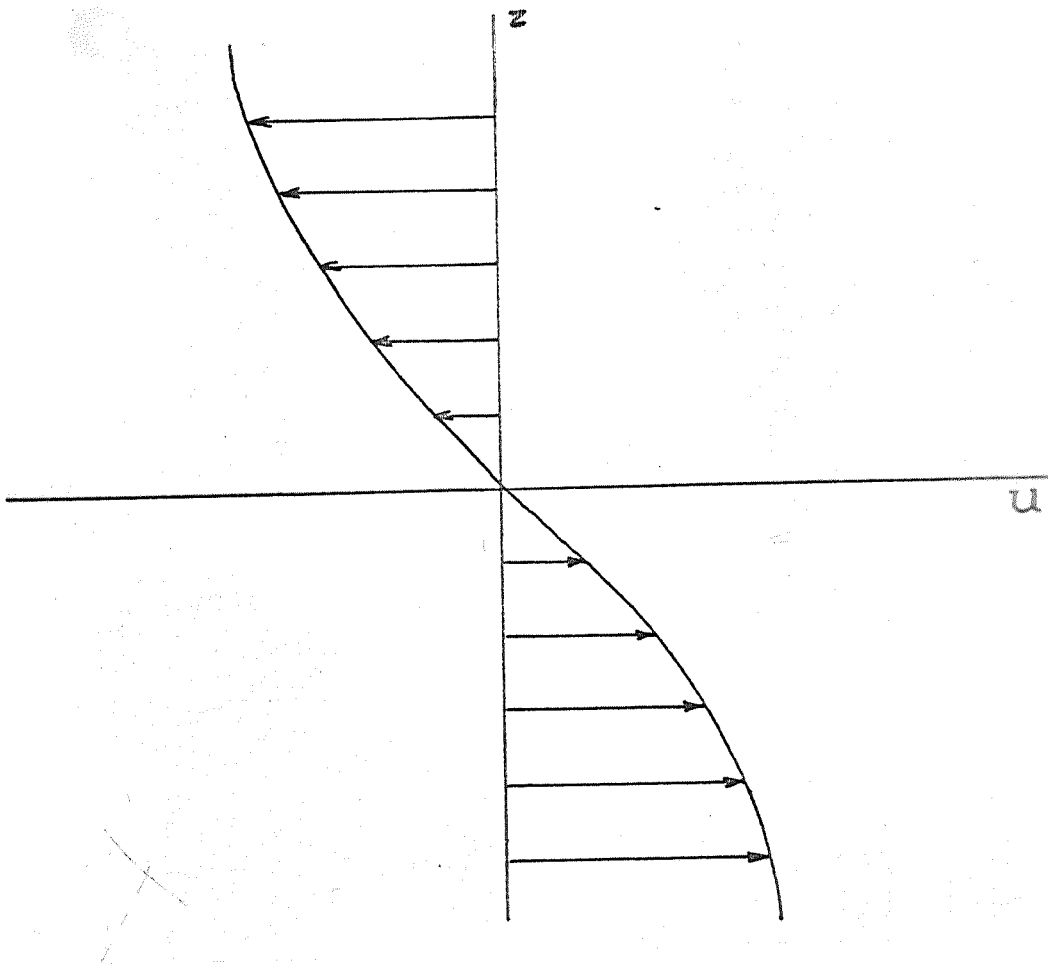

Figure 1. A profile of wind clipping.

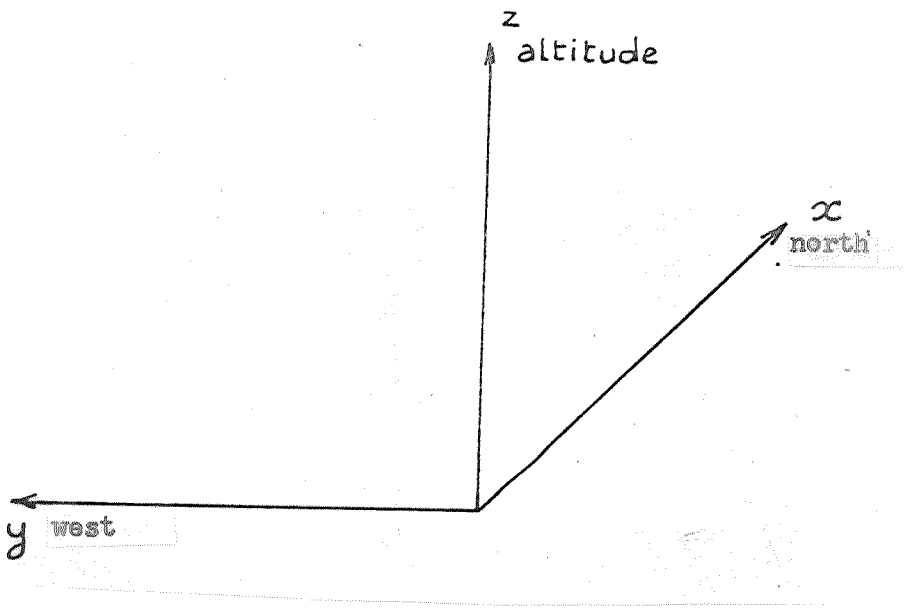

Figure 2. System of axes of coordinates.

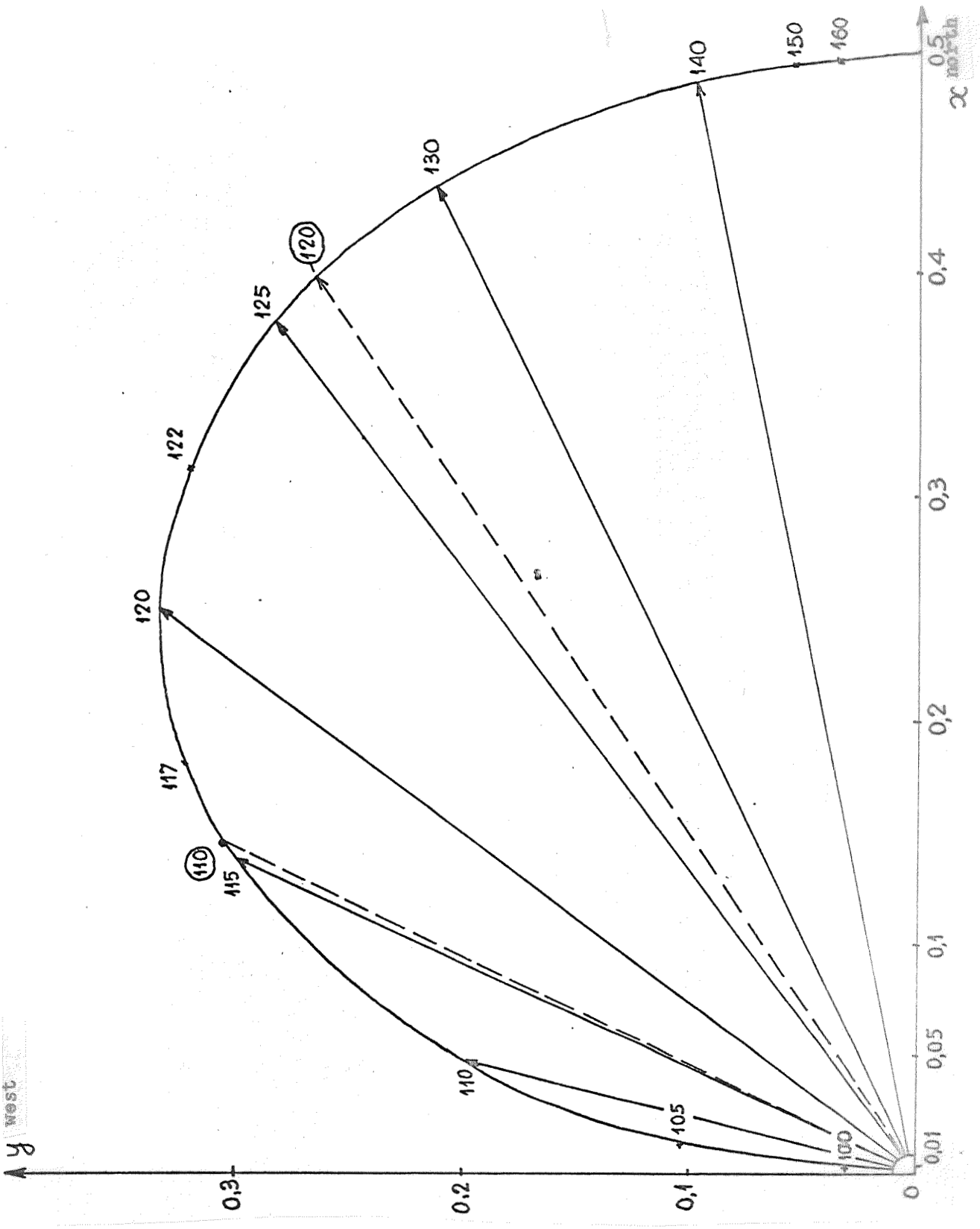

Figure 3. Variations of $\vec{B}$ as a function of the altitude for O^+; in dashes, the $\vec{B}$ vectors at 110 km and 120 km for O^+_2.

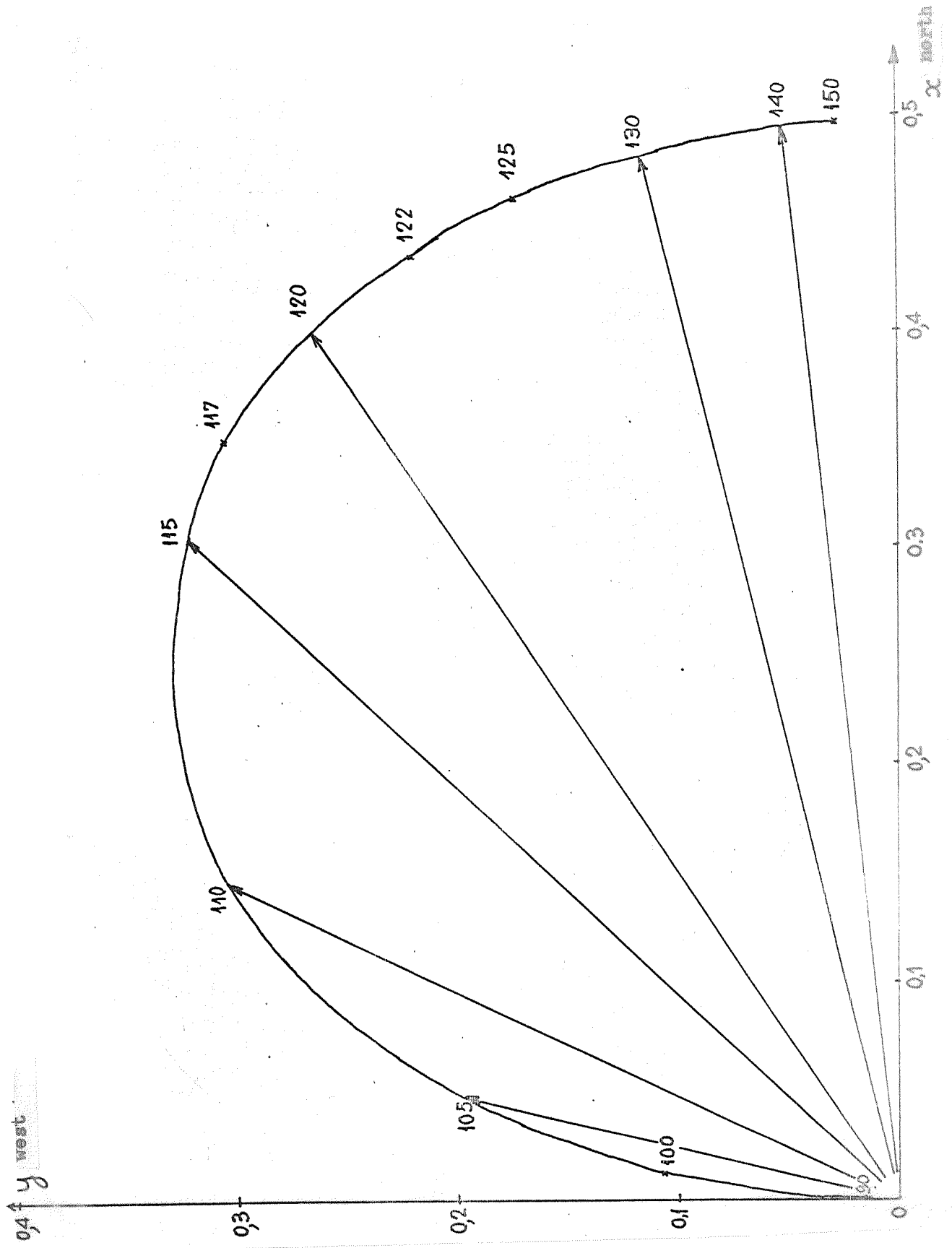

Figure 4. Variations of $\vec{B}$ as a function of Z for O^+_2.